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An Analysis of the Crash Experience of Passenger Cars Equipped with Antilock Braking Systems

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16. Abstract

Using data from FARS and Florida, Maryland, Missouri, and Pennsylvania, four "ABS-relevant" crash types were identified as follows: (1) rollovers, (2) side impacts with parked vehicles or fixed objects, (3) frontal impacts with parked vehicles or fixed objects, and (4) frontal impacts with another motor vehicle in transport. These crash types represented situations in which it was felt that ABS would be beneficial. The passenger car experiences in these four crash types were compared to a control group of crashes that are not expected to be affected by the presence of ABS. Detailed findings are provided for the four individual crash types, and on favorable vs. unfavorable road surfaces. The following findings were noted:

- o A significant reduction in non-fatal frontal impacts with another motor vehicle in transport crashes was associated with the presence of ABS;
- o Significant increases in non-fatal frontal impacts with parked vehicles or fixed objects and in non-fatal side impacts with parked vehicles or fixed objects were associated with the presence of ABS; and
- o Significant increases in fatal rollover crashes and in fatal side impacts with parked vehicles or fixed objects were associated with the presence of ABS.

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EXECUTIVE SUMMARY

Data from NHTSA's Fatal Accident Reporting System, supplemented by state crash files, were used to analyze the crash experience of antilock brake-equipped (ABS) and non-ABS-equipped passenger cars. State crash files for Florida, Maryland, Missouri, and Pennsylvania were chosen for analysis because these states collect and report, on their automated files, the vehicle identification number for crash-involved vehicles, an important characteristic for identifying specific makes/models and model years.

Four ABS-relevant crash types were identified as follows:

(1) rollovers,
(2) side impacts with parked vehicles or fixed objects,
(3) frontal impacts with parked vehicles or fixed objects, and
(4) frontal impacts with another motor vehicle in transport.

Crash types (1) and (2) generally involve driver loss of control, wherein ABS is expected to increase the vehicle's directional stability, allowing the driver to maintain greater control and remain on the roadway. Crash types (3) and (4) generally involve driver loss of control or the presumption that the driver did not apply the brakes or was unable to stop in time. The passenger car experiences in these four crash types were compared to a control group of crashes that are not expected to be affected by the presence of ABS.

Two types of ABS systems are presently available, rear-wheel antilock (RWAL) and all-wheel antilock (AWAL). Passenger cars are typically equipped with AWAL. Most light trucks and vans are RWAL-equipped, with AWAL-equipped light trucks becoming available only during the last few years. AWAL systems, operating on all four wheels, should increase directional stability and provide benefits in stopping distance on low friction surfaces experienced during rain and snow, while RWAL systems control only the rear wheels' braking, increasing directional stability.

The report provides detailed findings for all ABS-equipped passenger cars, for the four individual crash types, and on good vs. bad road surfaces. The following findings were noted:

- A significant reduction in non-fatal frontal impacts with another motor vehicle in transport crashes was associated with the presence of ABS;

- Significant increases in non-fatal frontal impacts with parked vehicles or fixed objects and in non-fatal side impacts with parked vehicles or fixed objects were associated with the presence of ABS; and

- Significant increases in fatal rollover crashes and in fatal side impacts with parked vehicles or fixed objects were associated with the presence of ABS.

PREFACE

The National Highway Traffic Safety Administration (NHTSA) recently completed this preliminary evaluation of the accident records of passenger cars equipped with antilock brake systems (ABS). The data comprise the initial years of exposure of the first groups of cars equipped with ABS. The analysis suggests that ABS has helped reduce vehicle-to-vehicle collisions on wet roads. Drivers of cars equipped with ABS are not colliding with other vehicles on wet roads as often as drivers of cars without ABS.

The study, however, shows that current ABS-equipped cars have a higher involvement rate, than cars without ABS, in single-vehicle, run-off-road crashes, that typically result in rollovers and collisions with trees or other fixed objects. The increase in run-off-road crashes approximately offsets the reduction of vehicle-to-vehicle collisions. Thus, NHTSA estimates that there has been little or no net accident reduction with ABS, to date. NHTSA's finding is consistent with the accident analysis published by the Insurance Institute for Highway Safety in January 1994.

The increase in run-off-road crashes is surprising in view of the good performance of ABS in stopping tests conducted by the agency and others. NHTSA is not yet certain that the observed increase is a direct consequence of the ABS system and/or the driver's interaction with ABS. NHTSA will continue to study the performance of current cars equipped with ABS to find out why run-off-road crashes have increased, and whether the problem is likely to persist in the future. The increase in run-off-road crashes might not be associated with all ABS systems; some current or future designs may perform differently than others. It might result, to some extent, from the inappropriate use of ABS systems by drivers, and it could change as drivers gain more experience with their ABS systems.

Several hypotheses have been suggested to explain the increase in run-off-road crashes. One possibility is that some drivers may negotiate curves or change lanes more aggressively because they believe ABS will enable them to stop in a shorter distance or retain control of their vehicle in extreme driving maneuvers. Other drivers, unaware of how ABS functions, may be pumping or releasing their brakes when the ABS begins to cycle. Another hypothesis is that drivers react to an imminent crash threat by abruptly braking and steering; cars without ABS would lock the front wheels and skid straight ahead, but cars equipped with ABS would remain steerable and could leave the road in those circumstances. It must be emphasized that none of these theories has been confirmed to date, by accident or test data, as an explanation for the increase in crashes.

NHTSA has established a program of data analyses and vehicle testing to obtain a better understanding of the performance of ABS in run-off-road crashes:

- National Accident Sampling System (NASS), Fatal Accident Reporting System (FARS) and narrative sections of North Carolina accident reports will be reviewed indepth for cases involving ABS-equipped cars which ran off the road.

- Drivers who complained to the NHTSA's Auto Safety Hotline about the performance of their ABS systems will be interviewed.

- Discussions will be held with NASS crash investigators and with police officers who drive ABS-equipped cruisers, or who have investigated crashes involving ABS-equipped vehicles, to gather their insights on possible causes of off-road crashes of ABS-equipped vehicles.

- Recent Human Factors literature will be reviewed to learn how drivers respond (steering and/or braking) to imminent crash threats.

- A research driving simulator will be used to determine average drivers' braking and/or steering responses to simulated crash threats. This study will yield the best objective data likely to be obtained as to what drivers actually do when confronted with an imminent crash threat.

- Combined braking and steering maneuver tests will be conducted with an ABS-equipped vehicle at NHTSA's Vehicle Research and Test Center to establish the range and bounds of maneuvers that can be successfully executed without a loss of directional control.

Follow-up reports will be released by NHTSA as the results of these efforts become available. NHTSA's ultimate goal is to identify appropriate actions that can be implemented by the Agency and/or industry to ensure safe, cost-effective braking technology.

In the meantime, NHTSA urges drivers to gain a better understanding of how their ABS systems operate, and to avoid using ABS brakes in a way that could increase accident risk:

- Many drivers think the main purpose of ABS is to reduce stopping distances. This is a serious misconception. ABS will only reduce stopping distances significantly in some special road conditions, but may increase distances in others.

- The principal goals of ABS are to prevent skidding and loss-of-control due to locked-wheel braking, and to allow a driver to steer the vehicle during hard braking.

- Drivers should not pump the brake pedal in cars equipped with ABS. This can defeat the purpose of ABS and may reduce braking capability.

- Drivers should know that the ABS system can make noise and vibrate the brake pedal when it is working. They should not take their foot off the brake pedal when they hear noise or feel pedal vibration.

- If a driver makes a car skid for reasons other than braking, such as going around a curve too quickly, ABS will not prevent or relieve the skid.

- Drivers of cars equipped with ABS must maintain the same distance behind vehicles they follow that they would have kept without ABS. They should not expect to stop more quickly because they have ABS.

- Drivers of cars equipped with ABS should not drive around curves, or change lanes, or perform other steering maneuvers any faster or more aggressively than they would have done without ABS. They should not expect ABS to improve their control in these maneuvers.

- Drivers should be aware that extreme steering maneuvers, executed while using ABS brakes, could steer the car off the road.

- ABS can significantly **lengthen** stopping distances on loose surfaces such as gravel or soft snow. Drivers should slow down and allow extra distance between vehicles under those conditions.

NHTSA is very interested in hearing from consumers about their experience with ABS systems, especially about cases where vehicles equipped with ABS ended up off the road. Consumers are urged to call NHTSA's **Auto Safety Hotline** at 1-800-424-9393 (202-366-0123 in the Washington, DC Metro Area). The **Auto Safety Hotline** can also provide information on the correct use and performance of ABS brakes.

INTRODUCTION

Section 2507 of the Highway Safety Act of 1991 (the Act) directs NHTSA to initiate rulemaking to consider the need for any additional brake performance standards , including antilock braking systems (ABS) for all passenger vehicles, i.e., passenger cars, light trucks, sport utility vehicles and vans weighing less than 10,000 pounds. NHTSA's determination of the viability of upgrading braking standards was to include consideration of a mandatory ABS requirement for all passenger vehicles.

Vehicle manufacturers have offered ABS to consumers either as a standard feature or as an option on millions of passenger cars and light trucks since approximately 1985. Most consumers appear to be knowledgeable about the availability of ABS-equipped vehicles, and many have chosen to purchase vehicles equipped with ABS. Manufacturers have actively advertised the availability of ABS on specific vehicle make/models and their potential safety benefits. In addition, several insurance companies offer discounts in premiums to consumers for ABS-equipped vehicles.

The objective of ABS is to automatically modulate braking pressure to prevent the vehicle's wheels from locking during braking. By preventing wheel lockup, ABS allows drivers to control their vehicles even in panic braking situations. Two types of ABS systems are presently available, all-wheel (AWAL) and rear wheel (RWAL). Passenger cars typically are equipped with AWAL, which is designed to keep all wheels of the vehicle rolling in an emergency braking situation. This allows the driver to properly steer the vehicle during the emergency situation and on some road surfaces, is intended to shorten the stopping distance. Most light trucks and vans with ABS are equipped with RWAL. RWAL prevents the rear wheels of these vehicles from "locking up" during emergency braking situations. Preventing lock up is designed to alleviate difficulties in directional control, typically experienced by light trucks and vans in emergency braking maneuvers. An increasing number of light trucks and vans are being equipped with AWAL. While more light trucks and vans are being equipped with AWAL, the total population of all registered light trucks and vans on the road today with AWAL remains very small.

Earlier work to study ABS effectiveness has been conducted by NHTSA's Office of Plans and Policy [1,2] . These studies by Kahane examined the effectiveness of RWAL ABS for light trucks and for passenger cars equipped with ABS. While RWAL was found to be

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[1] Kahane, Charles J., Ph.D., *Preliminary Evaluation of the Effectiveness of Rear-Wheel Antilock Brake Systems for Light Trucks*, December 1993.

[2] Kahane, Charles J., Ph.D., *Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars*, U. S. Department of Transportation, DOT-HS-808-206, December 1994.

effective in reducing the risk of nonfatal run-off-road crashes for light trucks, this finding did not carry over to fatal run-off-road crashes involving light trucks. Results were conflicting regarding the effect of RWAL in fatal multivehicle crashes and uncertain for nonfatal multivehicle crashes involving light trucks. Collisions with pedestrians, animals, bicyclists, trains, or on-road objects were found to be significantly reduced in light trucks with RWAL. Kahane's findings for passenger cars were also mixed. Both fatal and nonfatal multivehicle crashes were significantly reduced for passenger cars equipped with ABS. Fatal crashes with pedestrians and bicyclists were also found to be significantly reduced for passenger cars equipped with ABS. However, single vehicle, run-off-road crashes were found to be significantly increased for passenger cars equipped with ABS.

NHTSA's National Center for Statistics and Analysis (NCSA) has also studied ABS effectiveness for light trucks and vans [3]. NCSA's study found significant reductions in nonfatal rollover crashes and side impacts with fixed objects/parked vehicles for RWAL-equipped light trucks and vans; a significant reduction in nonfatal rollover crashes for AWAL-equipped light trucks and vans; along with mixed findings for fatal crashes. NCSA's study noted that the relatively small number of vehicles equipped with AWAL systems made it difficult to detect significant differences in crashes for these vehicles.

Studies on the effectiveness or impact of ABS have also been conducted by Folksam Research of the Chalmers University of Technology in Sweden [4] and the General Motors (GM) Research and Test Center [5]. To date, analyses for passenger cars involved crash data for what is believed to be an atypical group of vehicles with limited model years represented in the group. It is recommended that the impact of ABS in specific types of crashes be reexamined for passenger cars as more of these vehicles are purchased by greater numbers of consumers.

DATA SOURCES, SELECTING CRASHES AND IDENTIFYING VEHICLES

Data from NHTSA's Fatal Accident Reporting System (FARS) were used to analyze

[3] Hertz, E., Hilton, J., and Johnson, D. M., *An Analysis of the Crash Experience of Light Trucks Equipped with Antilock Braking Systems*, U. S. Department of Transportation, April 1995, in print.

[4] Kullgren A., Lie A., and Tingvall C., *The Effectiveness of ABS in Real Life Accidents*, #94 S4 O 07, presented at the 14th International Technical Conference on the Enhanced Safety of Vehicles, 1994.

[5] Evans, Leonard, Ph.D., *ABS and Relative Crash Risk Under Different Roadway, Weather, and Other Conditions*, [September 1994], SAE Technical Paper for presentation at SAE Annual Meeting in February 1995.

the fatal crash experience of ABS- and non-ABS-equipped passenger cars in this study. FARS began in 1975 and contains census data on the most severe traffic crashes, i.e., those resulting in a fatality. A crash is included in FARS when it involves a motor vehicle traveling on a trafficway open to the public and results in the death of an occupant of a vehicle or a nonmotorist within 30 days of the crash. FARS data for calendar years 1989-1993, the five most recent available years, were selected for this analysis. It was felt that the five most recent years of data would provide a sufficiently large sample of crashes involving both ABS- and non-ABS-equipped vehicles.

In addition to data from FARS, the five most recent years (1989-1993) available of crash files for the states of Florida, Missouri and Pennsylvania were chosen for analysis. Four years (1989-1992) of data were available from the state of Maryland. The files for Florida, Maryland, Pennsylvania, and Missouri contain data on all applicable crashes, ranging from property-damage-only to fatal, which occurred in each of these states. In addition, these states collect and report in their automated crash files the vehicle identification number (VIN) of crash-involved vehicles. This characteristic was important in selecting the state files that would be used in this analysis, as VIN was used to identify specific makes and models of passenger cars that were equipped with ABS and to identify comparable non-ABS vehicles.

Once FARS and the specific state files were selected for use in the analysis, the next step was to prepare each of these data files into treatment groups and a control group. The objective was to separate those crashes in which the passenger car(s) involved would be affected by the presence of ABS (i.e., treatment groups), from those crashes in which the passenger car(s) involved would not be affected by ABS (i.e., a control group). With this view in mind, certain crash types considered to be "ambiguous" were deleted. Ambiguities in characterizing crashes and the passenger cars involved in these crashes arose in the following areas: crash factors, driver factors, and environmental factors.

Crash factors: Crashes were considered ambiguous if, for example, it was uncertain whether ABS would have been beneficial in either avoiding the crash or reducing the severity of the crash. These ambiguous crashes included all first-event crashes with nonmotorists, animals, trains and other moving or nonfixed objects. Sideswipes in multivehicle collisions, head-on collisions and collisions with a vehicle on another roadway were also eliminated, as well as crashes in which the manner of collision was either unknown or characterized as "front-rear". Front-rear crashes are those in which the passenger cars have at least two impacts, one in front and one in the rear, as in a "pile-up" crash.

Driver factors: Passenger cars with an alcohol-impaired driver were also eliminated from the treatment groups, as it was considered questionable whether or not a driver under the influence would be able to use ABS properly in an emergency crash situation.[6]

Environmental factors: Crashes where the road condition (i.e., wet vs. dry, paved vs. unpaved) was unknown were deleted since one goal of the study was to determine the effect of ABS separately for favorable ("good", i.e., paved, free of debris, dry) and unfavorable ("bad", i.e., wet, snowy, icy, gravel, unpaved) road conditions.

Data for the remaining crashes were divided into four separate *treatment* groups as follows. Each of the four types of ABS-relevant crashes were defined according to the first event:

(1) rollovers (ROLL);

(2) side impacts with parked vehicles or fixed objects (SIDE), both considered "loss of control" situations;

(3) frontal impacts with another motor vehicle in transport (FRONT), i.e., "did not stop in time" situations; and

(4) frontal impacts with parked vehicles or fixed objects, i.e., "run-off-the-road" (ROR) situations, in which it is unclear whether either inability to stop and/or loss of control were major crash factors.

The passenger cars involved in these four treatment groups of crashes were considered to represent those for which there would be potential safety benefits of ABS.

The vehicles remaining in each of the data sets after the passenger cars involved in the above described crashes were removed comprised the control group. Crash involvement rates for each of the four treatment groups were analyzed and compared with the crash involvement rate for the control group. Passenger cars remaining in the control group consisted of those with rear damage only, e.g., in backed-into crashes, vehicles in multivehicle accidents (other than those in FRONT crashes) and non-rollover non-collisions.

Appendix A presents a schematic diagram which depicts allocating the crashes from FARS and state files into the four treatment groups and the control group, along with a listing of those ambiguous and other crashes that were eliminated from consideration. Appendix B presents tables of the proportion of ABS-equipped passenger cars for each of the four treatment groups and the control group for FARS and the state files.

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[6] A separate analysis including vehicles operated by alcohol-impaired drivers was conducted to determine if the findings of ABS effectiveness would be greatly affected. The results including alcohol-impaired drivers were almost identical to the results without these drivers.

Once the passenger cars in FARS and the state files were separated into treatment and control groups, it was necessary to identify which specific makes and models were equipped with ABS versus those that were not. This process was labor intensive and required collaboration among staff from various NHTSA offices. Information from automobile manufacturers and other informal sources was used to arrive at the final list of vehicles identified with or without ABS. The list of vehicles is included as Appendix C.

ANALYTICAL METHOD

A crash was considered ABS relevant if it might have been affected by the presence of ABS. Obviously, there is no direct way to count the crashes that were prevented, nor is there any way to determine if ABS was activated during the pre-crash maneuver. The basic approach, therefore, was to study the change in the proportion of crashes that were relevant, assuming that the presence or absence of ABS does not affect the occurrence of non-relevant crashes. The analytical methodology chosen for this study also controls for some demographic characteristics of the drivers along with environmental and vehicle factors.

As stated, four types of relevant crashes, also called treatment groups, were considered. These treatment groups are rollover (ROLL), side impact with a fixed object (SIDE), frontal impact with a fixed object (i.e., run-off-the-road crashes, ROR) and involvement in a two-car crash as the striking vehicle (FRONT). Separate analyses were conducted for crashes that occurred on favorable road conditions, "good" vs. unfavorable road conditions, "bad".

The basic technique was to consider the crash data as each observation corresponding to a vehicle that had been in a crash. Logistic regression [7] was used to test the effect of ABS on the probability that the crash was relevant, while controlling for other factors. This technique has been successfully used in other NCSA and NHTSA studies. [8,9]

Estimating the impact of ABS in reducing relevant crashes could be confounded by factors related to the driver, environment, crash, or other circumstances. To accurately estimate the impact of ABS, therefore, variables were included in the logistic regression to control for those factors, other than ABS, which could influence the proportion of relevant crashes. For example, if ABS-equipped passenger cars are more likely to be driven by

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[7] Hosmer, D. and Lemeshow, S., *Applied Logistic Regression*, John Wiley and Sons Publications, 1989.

[8] Klein, T. M., Hertz, E., Borener, S., *A Collection of Recent Analyses of Vehicle Weight and Safety*, U. S. Department of Transportation, DOT HS 807 677, May 1991.

[9] Klein, Terry M., *A Statistical Analysis of Vehicle Rollover Propensity and Vehicle Stability*, SAE Technical Paper Series 920584, The Society for Automotive Engineers, 1992]

younger males than by other segments of the driving population, then driver and vehicle characteristics could confound estimating the impact of ABS. As a result, the age and the sex of the driver, whether or not the crash occurred on a curved road segment (thereby increasing the difficulty in maneuvering to avoid a crash), whether the crash occurred in a rural vs. an urban setting, and the age of the vehicle were chosen for inclusion in the logistic regression model.

For each of the four states and FARS, for each type of road condition, and for each of the four types of treatment group crashes, a logistic regression was conducted of the form:

$$\text{logit}(p) = \text{AGE YOUNG MALE CURVED ABS RURAL VEH\_AGE}$$

where p is the probability of an ABS-relevant response, AGE is the age of the driver and YOUNG is an indicator variable that takes the value 1 if the driver is under 25, 0 otherwise. RURAL, an indicator of crashes occurring in rural vs. urban areas, was not available in Missouri and an indicator variable for speed limit of at least 45 mph was substituted.

Each of these models was run a second time with only those predictors that were statistically significant, while retaining ABS. This resulted in a final estimate of the coefficient for ABS and its standard error for each of the analyses, as shown in Table 1. Table 1 entries represent the change in the log odds ratio of an ABS-relevant to an ABS-nonrelevant crash in the presence of an ABS-equipped vehicle. **Negative coefficients represent a reduction that is associated with the presence of ABS.**

TABLE 1
Summary of Logistic Regressions for
Antilock-Equipped Passenger Cars

Rollover Crashes

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	**Std. Error**	**ABS Coeff.**	**Std. Error**
FARS	0.4288 *	0.1556	0.6605	0.3505
FLORIDA	0.4349 *	0.1298	0.5179	0.2902
MARYLAND	0.4396	0.8150	0.6369	0.7238
PENNSYLVANIA	0.0460	0.1340	0.0194	0.1591
MISSOURI	0.0419	0.1809	-0.1234	0.3049

Side Impact Crashes w/Parked Vehicle or Fixed Object

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	**Std. Error**	**ABS Coeff.**	**Std. Error**
FARS	0.6132 *	0.1737	0.7297 *	0.2661
FLORIDA	0.3557 *	0.0779	0.7157 *	0.1352
MARYLAND	0.2973 *	0.1065	0.2023	0.1413
PENNSYLVANIA	0.1963	0.2393	-0.5269	0.2751
MISSOURI	0.1866	0.1087	0.2729	0.1492

TABLE 1 (Continued)
Summary of Logistic Regressions for
Antilock-Equipped Passenger Cars

Front Impact Crashes w/ Another Vehicle in Transport

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	-0.0106	0.0756	-0.4244 *	0.1586
FLORIDA	-0.1060 *	0.0179	-0.5264 *	0.0423
MARYLAND	-0.0424	0.0541	-0.4399 *	0.0936
PENNSYLVANIA	-0.0454	0.0290	-0.2530 *	0.0502
MISSOURI	-0.1432 *	0.0343	-0.5039 *	0.0606

Front Impact Crashes w/ Parked Vehicle or Fixed Object

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.0826	0.1093	0.2180	0.2439
FLORIDA	0.1650 *	0.0467	0.2381 *	0.0933
MARYLAND	0.2019	0.1131	-0.0142	0.1592
PENNSYLVANIA	0.1238	0.0671	0.2479 *	0.0763
MISSOURI	-0.0738	0.0717	0.2353 *	0.1009

* Indicates Statistical Significance at the $\alpha = 0.05$ level, two-tailed test

It appears reasonable to assume that the effects of ABS should not differ dramatically from state to state. The results, in fact, did not appear to contradict this assumption, i.e., when the state results were examined in pairs, there were no pairs in which there were statistically significant results for the impact of ABS in opposite directions under the same circumstances. Therefore, the state ABS estimated coefficients were combined to form a single estimate, *the common log odds ratio*, for the same level of RESPONSE and SURFACE, using statistical methods described in Fleiss [10]. These results are displayed in Table 2 and represent crashes of all severities in the four states.

TABLE 2
Combined ABS Coefficients and Standard Errors for All Crashes

Crash Type	Surface Condition	ABS Coefficient	Standard Error	Effect
ROLL	Bad	0.13346	0.16832	NS
ROLL	Good	0.23805	0.09054	INCREASE
ROR	Bad	0.21796	0.04855	INCREASE
ROR	Good	0.10970	0.03239	INCREASE
SIDE	Bad	0.33501	0.07834	INCREASE
SIDE	Good	0.29305	0.05307	INCREASE
FRONT	Bad	-0.43365	0.02730	DECREASE
FRONT	Good	-0.09470	0.01348	DECREASE

LEGEND
ROLL = Rollover Crashes
SIDE = Side impact Crashes with parked vehicles or fixed objects.
FRONT = Frontal impact Crashes with another motor vehicle in transport.
ROR = Frontal impact Crashes with parked vehicles or fixed objects.
NS = Not significant

[10] Fleiss, Statistical Methods for Rates and Proportions, John Wiley & Sons, Inc., [1981].

These coefficients can be translated into the percentage change in the expected number of relevant crashes in the following way:

(1) Expected percentage change = 100* [exp(ABS coefficient)-1]

The justification for this formulation is as follows: Assume a group of vehicles, without ABS, will have N crashes of which p_0N are relevant and $(1-p_0)N$ are nonrelevant. With ABS there will still be $(1-p_0)N$ nonrelevant crashes. There will now be R relevant crashes where $R/[R+(1-p_0)N] = p_1$, i.e. $R = [p_1/(1-p_1)]N(1-p_0)$ since p_1 is the new proportion of relevant crashes. But p_0 and p_1 are related by

(2) $[p_1/(1-p_1)]/[p_0/(1-p_0)]$ = exp(ABS coefficient)

It follows that the expected percentage change in the number of relevant crashes due to ABS is $100*(R-p_0N)/(p_0N)$, or 100*[exp(coefficient)-1].

The proportion of ABS-relevant crashes could conceivably be reduced in two different ways: ABS-relevant crashes could be prevented or ABS-relevant crashes could be replaced by ABS-nonrelevant crashes. The assumption is being made that the presence of ABS has the potential to prevent the relevant crashes. This is probably generally true when the response is collision with another vehicle or fixed object. In the case of rollover, it is possible that the crash would still take place but be mitigated in the presence of ABS, that is, would become a nonrollover crash. However, since the proportion of rollover crashes is small, in equation (2), $1-p_0$ and $1-p_1$ are approximately 1 and we still obtain, approximately, p_1/p_0 = exp(ABS coefficient) so that$(p_1-p_0)/p_0$ = exp(ABS coefficient)-1.

Replacing the ABS coefficient c in (1) with c $\pm$ 1.96*(standard error of c) results in 95 percent confidence limits for the expected percentage change in relevant crashes. The results are displayed in Table 3.

TABLE 3
Estimated Percent Changes in Crash Types for ABS-Equipped Passenger Cars With 95 Percent Confidence Bounds

For All Crashes

Crash Type	Surface Condition	Percent Change	Lower Bound	Upper Bound
ROLL	Bad	+ 14	- 18	+ 59
ROLL	Good	+ 27	+ 6	+ 52
ROR	Bad	+ 24	+ 13	+ 37
ROR	Good	+ 12	+ 5	+ 19
SIDE	Bad	+ 40	+ 20	+ 63
SIDE	Good	+ 34	+ 21	+ 49
FRONT	Bad	- 35	- 39	- 32
FRONT	Good	- 9	- 11	- 7

For Fatal Crashes

Crash Type	Surface Condition	Percent Change	Lower Bound	Upper Bound
ROLL	Bad	+ 94	- 3	+285
ROLL	Good	+ 54	+ 13	+108
ROR	Bad	+ 24	- 23	+101
ROR	Good	+ 9	- 12	+ 35
SIDE	Bad	+107	+ 23	+249
SIDE	Good	+ 85	+ 31	+160
FRONT	Bad	- 35	- 52	- 11
FRONT	Good	- 1	- 15	+ 15

LEGEND
ROLL = Rollover Crashes
SIDE = Side impact Crashes with parked vehicles or fixed objects.
FRONT = Frontal impact Crashes with another motor vehicle in transport.
ROR = Frontal impact Crashes with parked vehicles or fixed objects.

How does the impact of the presence of ABS differ on "good" road surfaces vs. "bad" road surfaces? To answer this question, observe that for each combination of the 2 values of FATAL and the 4 crash types, Table 3 displays two estimates for the ABS coefficient, one for good surface and one for bad. For each of these estimates, there is an estimated standard error. Since these estimates are independent, it is straightforward to test if their difference is significantly different from 0 at $p = 0.05$. If it is not, they can be combined, again using the method described in Fleiss. These results are displayed in Table 4. In Table 4, the PERCENT CHANGE is the point estimate. The last column of Table 4 indicates if the ABS effect is significantly different from zero.

Table 5 summarizes the statistically significant expected percentage reductions with ABS, combining surfaces where it is valid to do so and presenting effects separately by surface condition where they are significantly different. Confidence limits are presented to provide the different levels of precision.

TABLE 4
Estimated Percent Change in Response Crashes in ABS Passenger Cars, When Surfaces Can Be Combined

Crash Severity	Crash Type	Percent Change	Statistically Significant
All Crashes	ROLL	+ 24	YES
All Crashes	ROR	+ 15	YES
All Crashes	SIDE	+ 36	YES
Fatal	ROLL	+ 60	YES
Fatal	ROR	+ 11	NO
Fatal	SIDE	+ 91	YES

TABLE 5
Summary of Statistically Significant Effects of ABS for Passenger Cars

Crash Severity	Crash Type	Surface Condition	Percent Change	Lower Bound	Upper Bound
All Crashes	ROLL	BOTH	+ 24	+ 6	+ 45
All Crashes	ROR	BOTH	+ 15	+ 9	+ 22
All Crashes	SIDE	BOTH	+ 36	+ 25	+ 48
All Crashes	FRONT	Bad	- 35	- 39	- 32
All Crashes	FRONT	Good	- 9	- 11	- 7
Fatal	ROLL	BOTH	+ 60	+ 21	+111
Fatal	SIDE	BOTH	+ 91	+ 44	+154
Fatal	FRONT	Bad	- 35	- 52	- 11

<u>LEGEND</u>
ROLL = Rollover Crashes
SIDE = Side impact Crashes with parked vehicles or fixed objects.
FRONT = Frontal impact Crashes with another motor vehicle in transport.
ROR = Frontal impact Crashes with parked vehicles or fixed objects.

DISCUSSION

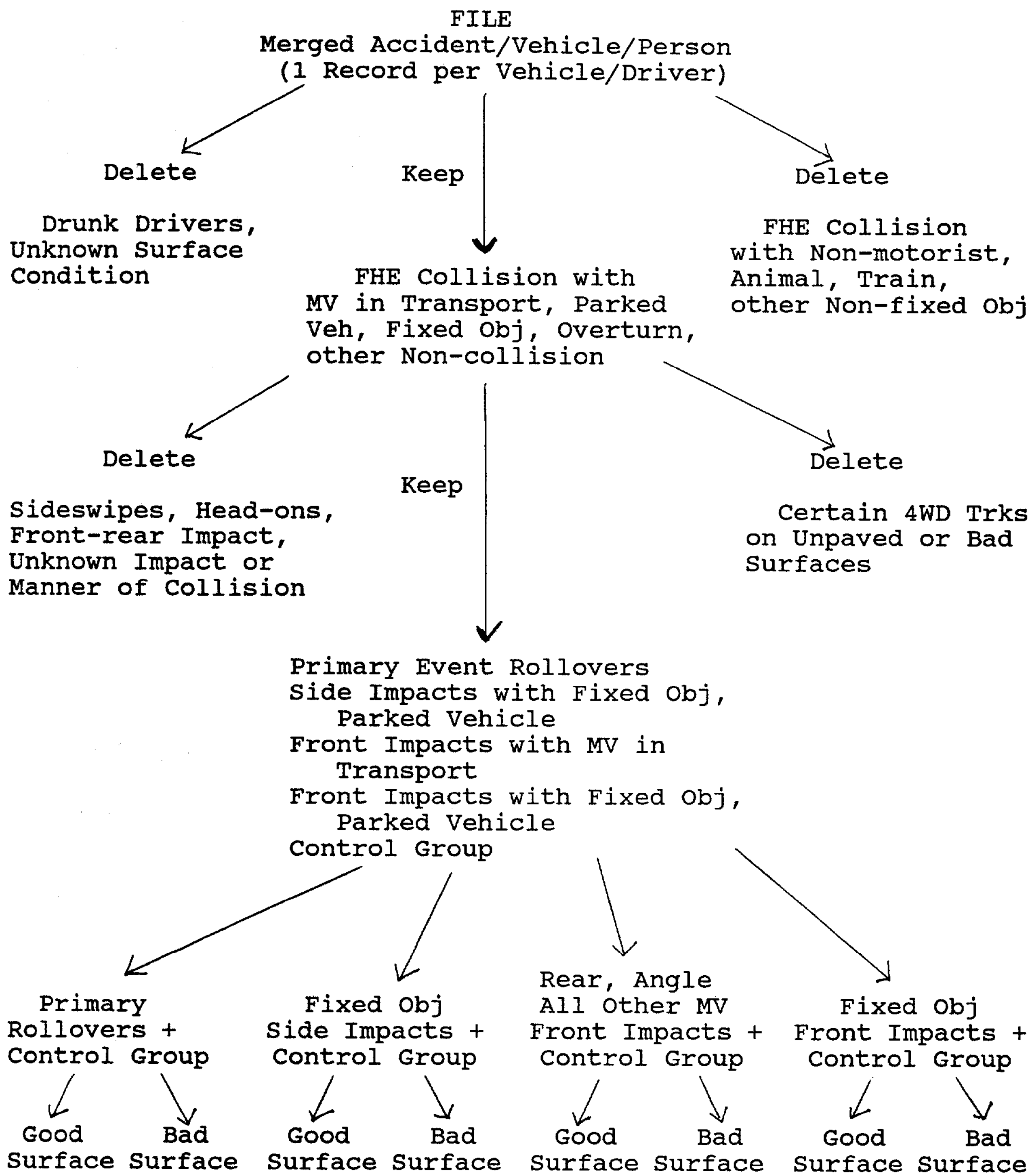
Of the four crash types, decreases in both fatal and all frontal crashes with another motor vehicle in transport were associated with the presence of ABS for passenger cars. For fatal crashes, the presence of ABS appears to be associated with a net increase. Three of the four crash types, rollovers, frontal impacts with parked vehicles or fixed objects, and side impacts with parked vehicles or fixed objects, had increases associated with the presence of ABS. While a decrease in fatal frontal impacts with another motor vehicle in transport was found, it was not found to be statistically significant, and therefore, may not offset the increases.

For all crashes, the presence of ABS appears to be associated with a decrease. All of this decrease comes from the significant percentage change in passenger car crashes involving frontal or did not stop time crashes. Similar to the results or fatal crashes, the remaining crashes types studied, rollovers, frontal or side impacts with parked vehicle or fixed objects, had increases associated with the presence of ABS.

These findings should be carefully considered, in light of several factors that could influence the determination of the effectiveness of ABS for passenger cars. Among these factors, driver actions or behavior, could be considered extremely critical. These results of effectiveness could change, as an increasing number of ABS-equipped passenger cars enter the vehicle fleet.

APPENDIX A

Schematic Diagram for Separating Databases Into ABS-relevant Crashes and non-ABS-relevant Crashes


FILE
Merged Accident/Vehicle/Person
(1 Record per Vehicle/Driver)
Delete
Drunk Drivers, Unknown Surface Condition
Keep
Delete
FHE Collision with Non-motorist, Animal, Train, other Non-fixed Obj
FHE Collision with MV in Transport, Parked Veh, Fixed Obj, Overturn, other Non-collision
Delete
Sideswipes, Head-ons, Front-rear Impact, Unknown Impact or Manner of Collision
Keep
Delete
Certain 4WD Trks on Unpaved or Bad Surfaces
Primary Event Rollovers
Side Impacts with Fixed Obj, Parked Vehicle
Front Impacts with MV in Transport
Front Impacts with Fixed Obj, Parked Vehicle
Control Group
Primary Rollovers + Control Group
Fixed Obj Side Impacts + Control Group
Rear, Angle All Other MV Front Impacts + Control Group
Fixed Obj Front Impacts + Control Group
Good Surface
Bad Surface
Good Surface
Bad Surface
Good Surface
Bad Surface
Good Surface
Bad Surface

APPENDIX B

Numbers of Passenger Cars Used in Analysis of ABS-relevant Crashes and non-ABS-relevant Crashes

Numbers of Passenger Cars Used in Analysis for ABS-relevant Crashes and non-ABS-relevant (Control) Crashes*

ROLLOVER CRASHES

	Data Source				
	FARS	Florida	Maryland	Pennsylvania	Missouri
No. of Passenger Cars	269	320	21	593	303
No. ABS Equipped	96	129	5	139	63
% ABS	35.7%	40.3%	23.8%	23.4%	20.8%

SIDE DAMAGE WITH FIXED OBJECT/ PARKED VEHICLE CRASHES

	Data Source				
	FARS	Florida	Maryland	Pennsylvania	Missouri
No. of Passenger Cars	270	1007	1055	198	837
No. ABS Equipped	103	441	240	42	218
% ABS	38.1%	43.8%	22.7%	21.2%	26.0%

FRONT DAMAGE WITH MOTOR VEHICLE IN TRANSPORT CRASHES

	Data Source				
	FARS	Florida	Maryland	Pennsylvania	Missouri
No. of Passenger Cars	2334	32505	4800	14316	13842
No. ABS Equipped	569	9184	833	3259	2511
% ABS	24.4%	28.3%	17.4%	22.8%	18.1%

FRONT DAMAGE WITH FIXED OBJECT/ PARKED VEHICLE CRASHES

	Data Source				
	FARS	Florida	Maryland	Pennsylvania	Missouri
No. of Passenger Cars	689	2944	916	2587	2481
No. ABS Equipped	193	1026	196	679	534
% ABS	28.0%	34.9%	21.4%	26.2%	21.5%

CONTROL GROUP CRASHES

	Data Source				
	FARS	Florida	Maryland	Pennsylvania	Missouri
No. of Passenger Cars	2594	40935	9357	25156	17048
No. ABS Equipped	682	13237	1909	6196	3777
% ABS	26.3%	32.3%	20.4%	24.6%	22.2%

* Actual number of vehicles will vary for each logistic regression as observations with missing values are deleted from the regression.

APPENDIX C

List of Passenger Cars Equipped w/ABS and Comparable Vehicles w/o ABS Used

List of Passenger Cars with and without ABS

With ABS		Without ABS	
Vehicle Make/Model	Model Year(s)	Vehicle Make/Model	Model Year(s)
Buick Skylark	92-94	Buick Skylark	89-91
Buick Le Sabre Limited	92-94	Buick Sabre Limited	89-91
Buick Regal Limited	92-94	Buick Regal Limited	89-91
Chevy Beretta/Corsica	92-94	Chevy Beretta/Corsica	89-91
Chevy Camaro	93-94	Chevy Camaro	91-92
Chevy Cavalier	92-94	Chevy Cavalier	89-91
Chevy Lumina Eurosport	92-94	Chevy Lumina Eurosport	90-91
Chevy Lumina Z34	92-94	Chevy Lumina Z34	91
Chrysler Imperial	90-92		
Lincoln Towncar	92	Lincoln Towncar	87-89
Lincoln Continental	86-92	Lincoln Continental	81-84
Lincoln Mark VII	86-92	Lincoln Mark VII	81-84
Chevy Caprice	91-92	Chevy Caprice	89-90
Chevy Corvette	86-92	Chevy Corvette	81-85
Cadillac Brougham	90-92	Cadillac Brougham	85-89
Cadillac Fleetwood/Deville	89-92	Cadillac Fleetwood/Deville	85-86
Oldsmobile Achieva	92-94	Oldsmobile Cutlass Calais	89-91
Oldsmobile 98	91-92	Oldsmobile 98	84-85
Acura Integra GS	90-92	Acura Integra RS/LS	88-91
Acura Legend	91-92	Acura Legend	86
Honda Accord EX	92	Honda Accord DX/LX	89-91

List of Passenger Cars with and without ABS - Continued

With ABS		Without ABS	
Vehicle Make/Model	Model Year(s)	Vehicle Make/Model	Model Year(s)
Honda Prelude SI	90-92	Honda Prelude	88-92
Audi 100/200	89-92	Audi 100/5000	84-86
BMW 3-Series	86-92	BMW 3-Series	81-85
BMW 5-Series	86-92	BMW 5-Series	81-85
BMW 6-Series	85-89	BMW 6-Series	81-84
BMW 7-Series	85-92	BMW 7-Series	81-84
Mercedes S/SL/SEL/SEC	85-92	Mercedes S/SL/SEL/SEC	81-84
Mercedes 200/300/400/500	86-92	Mercedes 200/300/400/500	81-85
Mercedes 190	89-92	Mercedes 190	83-85
Porsche 911	90-92	Porsche 911	85-88
Porsche 928	87-92	Porsche 928	81-85
Porsche 944 Turbo	90-92	Porsche 944 Turbo	84-87
Saab 900	90-92	Saab 900	87-89
Saab 9000	88-92	Saab 9000	83-87
Jaguar XJ Sedan	88-92	Jaguar XJ Sedan	85-87
Jaguar XJ-S Coupe	89-92	Jaguar XJ-S Coupe	85-88
Volvo 240	91-92	Volvo 240	88-90
Pontiac Firebird	93-94	Pontiac Firebird	91-92
Pontiac Grand Am SE	91-94	Pontiac Grand Am SE	89-90
Pontiac Grand Am GT	92-94	Pontiac Grand Am LE	89-91
Pontiac Sunbird	92-94	Pontiac Sunbird	89-91

List of Passenger Cars with and without ABS - Continued

With ABS		Without ABS	
Vehicle Make/Model	**Model Year(s)**	**Vehicle Make/Model**	**Model Year(s)**
Eagle Premier ES Limited	91-92	Eagle Premier ES	89-90
Honda Civic 4-Door EX	92-94	Honda Civic 4-Door 1600 EX	90-91
Honda Accord 4-Door SE	91 & 93		
Honda Accord 2-Door SE	93		